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INFILTRATION AND WATER REPELLENCY IN GRANITIC SOILS

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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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CONTENTS

INTRODUCTION

Affinity for water is one of several soil properties that determine infiltration rates. In some soils, particularly sandy soils, there are zones that have little affinity for water and that, in fact, repel water because surfaces of the minerals in such zones are coated with hydrophobic organic substances. The extent to which water repellency affects infiltration depends not only on its severity, but also on its distribution within the soil mantle. If repellency is mild or is limited to a few scattered patches, its effect on infiltration is minor. At the other extreme, no infiltration is possible if the entire soil surface is severely repellent.

The mechanisms involved in the formation of water-repellent soils are not well understood, partly because the hydrophobic compounds have not been identified. These compounds are formed and released from plants and plant residues by decomposition and pyrolysis. They may be formed in the soil by fungi and other microflora (Bond and Harris 1964) or they may move into the soil after formation elsewhere.

It is known that hydrophobic compounds are released by combustion of litter and move as vapors into the soil (DeBano 1966). Similarly, the high temperatures induced by fire pyrolyze soil organic matter and vaporize hydrophobic compounds already present in the surface soil. A portion of these vapors escape to the atmosphere, but some diffuse downward in the soil to condense on cooler mineral surfaces (DeBano and Krammes 1966). This action results in a soil profile that has a wettable surface but a layer of water-repellent soil exists an inch or so below the soil surface. Infiltration into such a soil may cease entirely when the wettable surface layer becomes saturated.

The following hypothesis is offered to explain water repellency that has not formed in place and has not been caused by fire. Decomposition of plant litter may release compounds that are carried by water into the soil where they are absorbed on mineral surfaces and become hydrophobic as the soil dries. This process is probably slow; several years may be required for formation of severe repellency. Its existence may be difficult to prove.

METHODS

This report is based on observations made on 92 plots on granitic soils at elevations between 5,500 and 9,500 feet in the Carson Range east and northeast of Lake Tahoe. Most of the study sites were in the Jeffrey pine type, and ranged from fully stocked stands of small sawtimber to open brushfields no longer supporting timber. The remainder were in an open lodgepole *(P. contorta)* and western white pine *(P. monticola)* stand on the west face of Slide Mountain.

Infiltrometer

Preliminary investigations revealed that water repellency was usually most severe at the soil surface and that any disturbance of the surface soil (e.g., that caused by driving a plot frame or infiltrometer ring into the soil) could rupture the repellent layer and allow water to bypass it.

To minimize errors due to soil disturbance, we developed a special infiltrometer. (See appendix for construction details.) This infiltrometer consists of a rainfall simulator, similar to the raindrop-producing unit developed by Chow and Harbaugh (1965), and a runoff-collecting trough. The rainfall simulator applies water uniformly to a fixed area (3.7 square feet) at a controlled rate. No plot frame is used; the boundaries of the plot are determined by the area of water application. Plot runoff is caught by a trough at the downhill edge of the area of application. This runoff collector is installed slightly below the soil surface and (when necessary) sealed with caulking compound.

RESULTS AND DISCUSSION

All granitic soils sampled in this study fell within the sand and loamy sand textural classes. Sand content of the surface soil of the plots ranged from 80 to 95 percent and averaged 89 percent. Clay content ranged from 2.4 to 4.5 percent and averaged 3.5 percent. With few exceptions soil bulk density was less than 1.6 g./cc.; and generally less than 1.4 g./cc. The infiltration capacity of such coarse, porous soils is excellent in the absence of water repellency. However, water repellency was encountered on most of the plots, varying in degree from a barely perceptible slowing of the wet front to a virtually complete halting of the wet front. Where a high degree of water repellency was present, its distribution in the soil profile ranged from a few isolated patches to a thick, continuous layer.

Wetting Patterns

The wetting pattern in the soil of each plot was exposed by digging a trench across the middle of the plot after water had been applied for 30 minutes. Although no two wetting patterns were exactly alike, they could be classified into eight general types, depending on size, continuity, and location of water-repellent zones (fig. 1).

Pattern 1 is the typical wetting pattern of homogeneous, wettable soils. This pattern was found only in openings devoid of vegetation and litter.

Pattern 2 occurred where the soil surface was covered by litter. Live plants were usually present. The wet front is irregular because the soil is not homogeneous. The irregularity is due primarily to variations in soil porosity, but it is believed that variations in soil wettability are partially responsible in some cases.

In Pattern 3, there were isolated patches of dry soil within the wetted zone but not at the soil surface. The dry patches occasionally surrounded roots from nearby shrubs or trees, but not all roots were surrounded by dry soil, nor were the dry patches confined to the vicinity of roots. This pattern usually, but not invariably, occurred in bare openings. Little or no runoff was produced by plots having Patterns 1, 2, or 3.

In Pattern 4, portions of the surface soil remained dry and were bypassed by the wet front. Litter was always present over the dry patches. When live vegetation was present, it was usually growing on the wetted portions of the soil surface. Dry patches varied widely in area and thickness, and the amount of runoff produced varied accordingly.

In Pattern 5, there was a discontinuous water-repellent layer 1 to 3 inches below the bare soil surface. The surface soil was readily-wettable and breaks in the water-repellent layer allowed the wet front to penetrate the wettable soil below the layer. Runoff from plots with this pattern was severe unless there were many breaks in the water-repellent layer.

Pattern 6 was found on litter-covered plots where the discontinuous water-repellent layer was at the soil surface. This pattern was rarely found when there were live shrubs on the plot. Runoff from plots with this pattern varied widely but tended to be less than that of plots with Pattern 5 because there were usually more breaks in the water-repellent layers formed under litter.

Pattern 7 was found in bare plots where there was a continuous water-repellent layer 1 to 3 inches below the soil surface. Runoff was severe because the surface layer of soil provided the only available storage for water.

Pattern 8 is the extreme case where there were no breaks in a water-repellent layer at the surface. This pattern was found under pine litter only on plots that had no understory. Pattern 8 produced more runoff than any other because the only available water storage was in the litter that--being somewhat water repellent also--held very little water.

Infiltration Curves

There was little or no runoff from the plots with wetting patterns 1, 2, or 3. Many of these plots appeared to have infiltration capacities well in excess of 4.7 inches/hr., the application rate. Runoff from plots with Pattern 4 was generally slight because the wettable portions of the soil surface absorbed the runoff from the water-repellent portions. However, if more than about two-thirds of the soil surface remained dry during the 30-minute application of water, runoff was great enough to indicate that infiltration capacity was less than the rate of application. All plots with wetting Patterns 5 through 8 produced appreciable runoff.

Typical infiltration curves are shown in figures 2 and 3. These curves are based on actual measurement of runoff during the 30-minute application. Curve 4 is the average of two plots with wetting Pattern 4 on which more than two-thirds of the soil surface remained dry during the 30-minute test. The gradual increase during the latter part of the test is typical of plots with incomplete water repellency. In fact, runoff began at about 3 minutes and ceased after about 15 minutes on four plots in this category. This phenomenon is believed to be caused by mild water repellency in the wettable portions of the soil surface. Once the wet front penetrates the slowly-wettable portions of the soil surface and enters the more absorbent soil below, its rate of advance increases.

Curve 6A is the average of infiltration rates on three plots that had wetting Pattern 6 and many breaks in the water-repellent layer. Curve 6B is based on four plots that had few breaks. The curves are basically similar, but infiltration is greater in plots that water penetrated at more points.

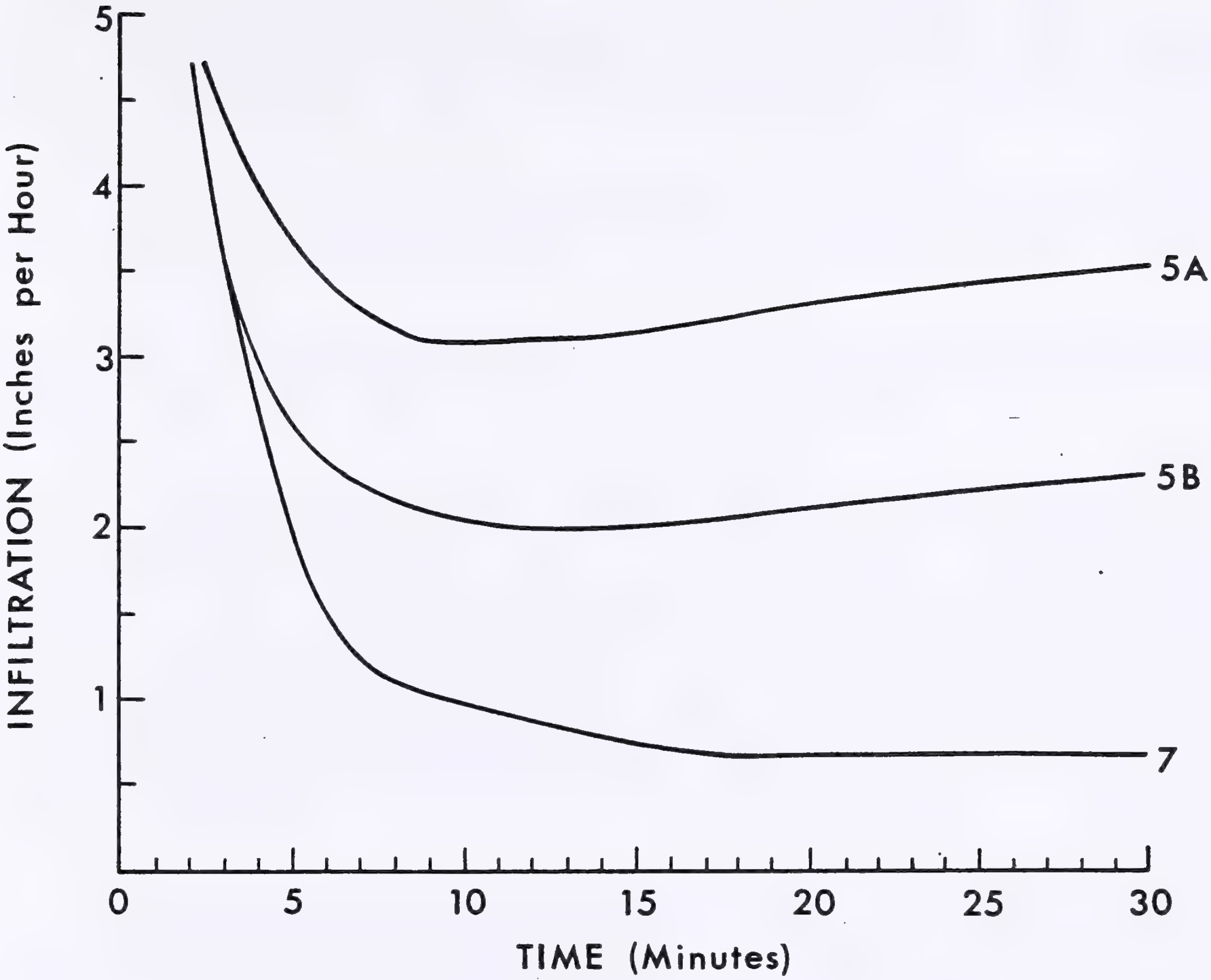

Figure 3.--Infiltration into bare water-repellent soils.

Curve 7 is from a plot having a continuous subsurface water-repellent layer (Pattern 7). The initially high infiltration is due to the absorbent surface soil. Once the soil above the water-repellent layer was thoroughly wetted, infiltration did not cease entirely--as might be expected--because of lateral flow in the surface soil, but also because of slow penetration into the repellent layer.

Ground Cover Effects

The selection of the number of plots on each ground cover type was based on frequency of occurrence of the cover types, and on variations in infiltration within the cover type. Cover types that had the most widely varying infiltration rates were sampled more intensively. The number of plots is too small to allow valid statistical tests

The plot that absorbed the most water (1.05 inches) had a small clump of bunchgrass *(Stipa* sp.*)* under which the soil was wettable enough to allow penetration of the wet front. Pinemat manzanita *(Arctostaphylos nevadensis)* was growing on another plot and water was able to penetrate along some of its roots but this plot absorbed only 0.75 inch of applied water.

The other four plots were devoid of live vegetation. Three of these plots absorbed 0.30 to 0.55 inch of water because water penetrated the water-repellent layer at one or two points. There was no soil wetting whatsoever on one plot, and only 0.13 inch of water was absorbed by its litter.

Shrubs.--Average runoff from the shrub plots was much lower that that from pine plots because soils on such sites were less repellent. Although patches of dry surface soil (Pattern 4) were found on most of the shrub plots after the water application test, they were never extensive enough to cause runoff in excess of 0.75 inch.

Most shrub plots were close to pine trees and had varying amounts of pine needles on them. The litter on squaw carpet *(Ceanothus prostratus)*, pinemat manzanita, and bitterbrush *(Purshia tridentata)* plots usually contained more pine needles than shrub leaves; apparently these species produce relatively little litter, but efficiently trap pine needles. Tobaccobrush *(C. velutinus)* and greenleaf manzanita *(A. patula)* are more prolific litter producers, and pine needles were usually a minor constituent of litter on plots dominated by these species. Because of the admixture of pine needles, it is uncertain how much of the water repellency was derived from shrub species. However, the results suggest that shrubs rarely cause serious water repellency; on the contrary, they increase infiltration into soil rendered water repellent by pine residues. The prostrate shrubs, squaw carpet and pinemat manzanita, seem to be especially effective in disrupting water repellency because their roots penetrate the surface soil at many points.

Of the five shrub species tested, tobaccobrush produced the highest average runoff and probably had the most water-repellent soil. Greenleaf manzanita had the lowest average runoff and the least repellent soil. Since the amounts of pine litter were approximately equal on plots of both species, it appears that greenleaf manzanita is superior to tobaccobrush with respect to infiltration and soil wettability. Since plots of the other three shrub species generally had more pine litter than tobaccobrush or greenleaf manzanita, no judgment could be made as to their respective potentials to induce water repellency.

Bare ground.--There was at least one bare plot in the vicinity of each litter-covered plot. These 22 plots were devoid of live vegetation. There were pine needles on some of them but usually these had been cast within the past year and rarely covered more than 10 percent of the plot surface. Without exception, the soil surface was highly absorbent if no litter cover was present. However, there were varying amounts of water-repellent soils below the surface of 11 plots.

Runoff from the 11 plots that had no discernible water repellency (wetting Pattern 1) did not exceed 0.16 inch of water, and six of them produced no runoff at all. Seven plots had patches or pockets of dry soil above the wet front (Pattern 3); total infiltration during the 30-minute test varied from 1.65 to 1.89 inches on these plots. Two plots had discontinuous water-repellent layers about 2 inches below the soil surface (Pattern 5) and absorbed 1.18 and 1.52 inches of water. Two plots had continuous water-repellent layers 1 to 2 inches below the soil surface (Pattern 7) and absorbed only 0.65 and 0.80 inch of the applied water.

CONCLUSIONS

Within the geographical area covered by this study (and probably in many similar areas) water repellency is a major limiting factor in the capacity of granitic soils to absorb high-intensity summer rainfall. Other limiting factors are: (1) Inadequate moisture storage capacity due to thin soil, (2) surface sealing caused by raindrop impact on soil surfaces unprotected by litter and vegetative cover, and (3) low porosity due to compaction caused mainly by human activity. Although this report is concerned primarily with water repellency, it is not meant to imply that the other limiting factors listed are unimportant. On the contrary, they cause serious problems on steep, poorly-vegetated slopes and on heavily-used areas. However, water repellency can curtail infiltration into soils that have sufficient depth, porosity, and cover to absorb high-intensity rain as fast as it falls; and it can further reduce infiltration of water into soils where one or more of the other limiting factors are present.

At times, even though no water repellency was found at the surface of bare soil, severe repellency was found below the surface. Some repellency may be residual from past fires, but much of it is believed to be caused by fungal activity on plant roots that frequently occupy the soil under bare openings. If the subsurface repellent layer is continuous and unbroken, infiltration is limited to the storage capacity of the wettable surface layer and severe runoff and erosion will occur during high-intensity storms. The best control in such openings would be obtained by establishing plants in them. Establishment of plants on such sites is difficult, but could be facilitated by destroying the live roots already present under the bare openings.

Water repellency does not appear to be a problem under shrub cover because it is broken up by numerous roots, rodent burrows, and by other means not yet identified.

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APPENDIX

Infiltrometer Construction and Operation

In the following discussion, the numbers enclosed by brackets refer to the numbers in figure 4. The water supply [1], a 5-gallon polyethylene bottle with a 1/2-inch tubulature, rests on a 4-inch-high styrofoam block [2] placed on top of the water chamber [3]. A 16-inch-long, 1/8-inch i.d. acrylic tube [4] passes through the bottle cap and allows air to enter at a point about 1 inch above the bottom of the bottle, thus maintaining a relatively constant head. A Manostat (Cat. No. 36-541-30) flow meter [5] is used to measure flow. The 3/8-inch i.d. plastic tubing [6] is connected to the water chamber by a polyethylene quick-disconnect coupler. Flow rate is controlled by an ordinary screw-type tubing clamp [7]. The 6-inch-long 1/8-inch i.d. acrylic tube [8], connected to the water chamber by a polyethylene quick-disconnect, serves three functions: it allows air to escape the water chamber during filling, it indicates water pressure within the chamber, and it facilitates draining.

The water chamber (fig. 5) is similar to the one described by Chow and Harbaugh (1965), but has been modified for field use. It is constructed of plexiglas bolted to angle aluminum. The numbers in parentheses in the figure indicate the number of pieces needed. For added strength, four plexiglas spacers are placed as shown. All joints are sealed with caulking compound. Each dot on the bottom view represents a 3/4-inch-long 23-gage stainless steel tube.[1] These 517 raindrop-producing tubes project 1/8 inch above and 3/8 inch below the lower plexiglas sheet and are held in place with a small amount of epoxy cement. Holes for the tubes were drilled with a No. 71 wire gage drill. Holes for the 5-40 bolts were drilled oversize to 5/32 inch to avoid stress on the plexiglas and to facilitate assembly.

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[1]0.025-inch o.d., 0.00625-inch wall thickness, obtained from Vita Needle Co., Needham, Mass. 02192.

The water chamber must be as level as possible. The support frame (fig. 6) is adjustable so that the water chamber can be leveled on slopes up to 60 percent. This could be increased up to about 85 percent by increasing the length of the slots in the slotted bars [9]. The bolts that attach the upright members to the base are secured with locknuts and are left loose enough to allow the limited rotation required for leveling. The collector trough [10] is made from a single piece of sheet steel bent as indicated in figure 6.

The infiltrometer is set up and operated as follows. The water applicator is placed over the area to be tested. A sensitive level is placed on the water chamber and the chamber is leveled along both axes by means of the leveling mechanism [9] and by moving the applicator slightly, if necessary. On steep or slippery slopes the applicator is held in position by stakes driven into the ground inside the upper two corners of the base. After the applicator has been positioned, the runoff collecting trough [10] is installed with its upper edge directly below the lower edge of the applicator. It should be installed slightly below the soil surface, and, if necessary, the uphill edge sealed to the soil surface with caulking compound. A small hole is dug under the outlet of the trough to allow placement of a tin can such as a 2- or 3-pound coffee can [11].

The reservoir is filled and connected to the water chamber. The tubing clamp is opened to allow free flow of water into the water chamber. Few raindrops are produced while the chamber is filling. As soon as the chamber is filled and water moves into the manometer [8], the tubing clamp is quickly adjusted to the desired flow. Rainfall commences as soon as water appears in the manometer and, from then on, its rate responds almost instantaneously to changes in flow-meter readings. It is usually necessary to readjust the tubing clamp from time to time. The reservoir can be refilled during the test if the flow rate is kept reasonably constant by means of the tubing clamp. Runoff into the tin can is measured at desired intervals in a 1,000-ml. graduated cylinder. At the end of the test, water application can be stopped abruptly by kinking the supply tubing and closing the tubing clamp.

Some clogging of the steel tubes can be expected, but can be minimized by using only clean water and by using a screened funnel for filling the reservoir. Distilled water might give better results, but we used tapwater from city supplies and campgrounds and experienced only minor clogging. If a tube clogs, it can be cleaned by pushing a small steel wire up the bore of the tube.

Rainfall intensities from about 1/2 inch per hour to about 10 inches per hour can be obtained with this infiltrometer. The infiltrometer was calibrated at several intensities by operating it on a metal sheet; the results agreed closely with the flow-meter manufacturer's calibration chart.

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1971. Infiltration and water repellency in granitic soils, USDA Forest Serv. Res. Pap. INT-111, 20 p., illus.

The granitic soils of the Carson Range of the Sierra Nevada are often water repellent to some degree. Under chaparral cover, water repellency tends to be patchy and rarely impedes infiltration appreciably. Under coniferous litter, it tends to form a continuous layer in the surface soil and, on some sites, can curtail infiltration and cause accelerated runoff.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

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